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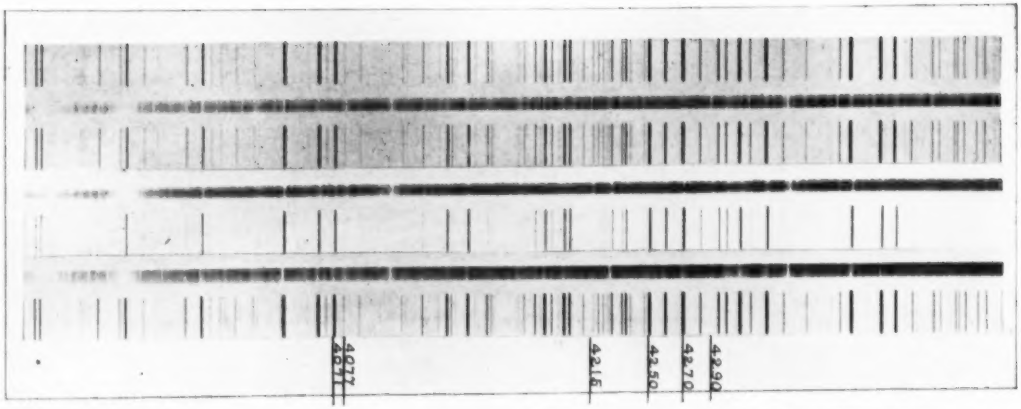
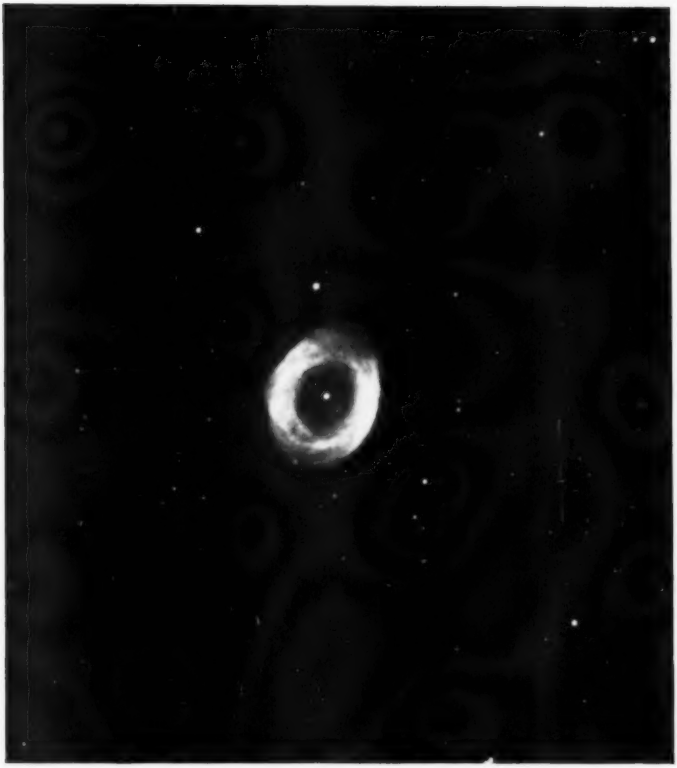
PLATE III



Spectra of three stars showing absolute magnitude effect. Upper spectrum, Polaris (Alpha Ursae Min); middle spectrum, Gamma Persei; bottom spectrum, Zeta Ursae Maioris. Note the strength of 4077, 4215 and 4290 in Polaris as compared with 4070, 4250 and 4270, respectively. Compare the same lines in the bottom spectrum. Polaris is a giant. Zeta Ursae Maioris a dwarf star.

Journal of the Royal Astronomical Society of Canada, 1927.

PLATE IV



The Ring Nebula in Lyra. Nebulae of this kind are always associated with a central star, and the distances are obtained by the method of parallax applied to the central star. As a class their distances are of the order of a few hundred light years.

Journal of the Royal Astronomical Society of Canada, 1927.

PLATE V

Part of a "network" or filamentary nebula in Cygnus. Notice that the stars are much more numerous on one side of the nebula than on the other. Astronomers believe that dark matter obscures the stars on the one side, and by finding the magnitude where the number of stars diminishes, an estimate of the distance is obtained.

Journal of the Royal Astronomical Society of Canada, 1927.

PLATE VI

The great cluster in Hercules. The plate is reproduced from a short-exposure photograph made with the 7½-inch telescope at Victoria. From long exposures, it is estimated that 50,000 or more stars exist in the cluster. The distance to the cluster (about 35000 light-years) is obtained from a study of the variable stars found in it.

Journal of the Royal Astronomical Society of Canada, 1927.

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THE CONFINES OF THE UNIVERSE*

BY R. K. YOUNG

WE think of space as infinite and consequently picture the universe as unlimited. The Theory of Relativity tells us that we can never hope to get evidence of matter outside a definite sphere. Each observer, according to this theory, is at the centre of his sphere of observation, which moves with him as a rainbow seems to move when the one who sees it changes his position. The sphere is so large that our most powerful telescopes have penetrated but a short way toward the surface, and I am using the word "confine" in this paper as signifying the utmost bounds to which astronomical observation has been able to reach.

In Lord Tennyson's poem "Ulysses" there occur the following lines:—

> I am a part of all that I have met;
> Yet all experience is an arch wherethro'
> Gleams that untravell'd world whose margin fades
> For ever and forever when I move.

The universe is just as large as our experience, and its margin continues to fade with the advance of knowledge. Creation is widening in man's view all the time. When Ulysses lived the confines of the universe were very limited. The Straits of Gibraltar and the Atlantic Ocean were on the borders of the great beyond, but now we measure distances in millions of light years. It is my purpose to outline the methods by which the distances in the

*Lecture delivered before the Ontario Educational Association, April 26, 1927.

universe are measured, the dimensions of the solar system determined, the scale of the universe fixed.

Direct measurement is the most fundamental method we have for getting distances and when applied to the earth leads to the exact science of geodesy. The lengths of arc on the surface of the earth, both in latitude and in longitude, are measured by chaining off the distances. Errors in the length of the measuring chain, temperature effects, errors in the end-placings of the standard, personal bias have to be guarded against; but measures of this kind have been made so accurate that the equatorial radius of the earth, 3,963.34 miles is known within 500 feet.

The surveyor uses another method of finding distances when the object is inaccessible, and this method the astronomer also

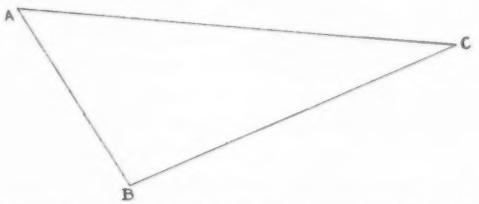

Fig. 1. Surveyor's method of finding the distance of an object. AB is measured as well as angles CBA and CAB. The distances AC and BC are then computed.

employs. In Figure 1 *A* and *B* are two points the observer can reach, and *C* a third point whose distance from *A* and *B* is required. *C* may or may not be readily reached from *A* or *B*. It may be on the far side of a stream, it may be a mountain peak or in astronomy it may be some heavenly body. The observer measures *AB* as well as the angles *CAB* and *CBA*. Having given these three quantities, it is a simple matter of geometry to compute the sides *AC* and *BC*. The method is much complicated in astronomy by the fact that rays of light are bent, or refracted, before reaching the observer, and also by the motions of the points *A* and *B*. These difficulties can be overcome, and the method is used to determine the distance to the moon, which comes out about 238,000 miles. Light would travel this distance in one and one-third seconds. The moon is the closest of all astronomical bodies.

The base line *AB* is the essential element in the method. The

shorter this is relative to the lengths of the sides AC and BC, the more uncertainty there will be in the calculated distance. In other words, the farther C is away, in proportion to the length of AB, or the smaller the angle at C, the greater will be the percentage error. In astronomical work C is always very remote. Even in the case of the moon, the closest of all astronomical bodies, as already remarked, the angle is about one degree, when the points of observation are taken as far apart as is conveniently possible. When we measure the distance to the sun the angle is less than nine seconds of arc. The sun is a difficult object to measure because its edge is somewhat diffuse, and hence the method is very inaccurate.

Fortunately we have found other ways of getting the sun's distance, in fact there are a dozen methods, all of which yield practically the same result, but I shall describe only one. The interagreement of the various methods assures us that our results are correct. From Kepler's Third Law, which states that the squares of the periodic times of the revolutions of the planets about the sun are proportional to the cubes of the mean distances, it follows that when the distance of one of the planets has been found the rest can be computed. It is only necessary for us to obtain the distance of the one which is easiest to measure, and that one is the planet that comes closest to the earth. Mars at opposition does very well, but some of the little asteroids, or planetoids as they are sometimes called, are better still. There is one of these, called Eros, which comes very near to the earth. The last close approach was in 1901, when it was about 30 million miles away. Many observations were taken at that time and the distance measured. The mean distance from the earth to the sun as computed from these measures came out about 92,870,000 miles, though the figure 7 is a little uncertain. Eros will come within sixteen million miles in 1931, and preparations are already being made for determining its distance.

It takes light a little over eight minutes (498 seconds) to come from the sun to the earth, and the most remote planet in the solar system is at a distance which a light ray covers in four hours and nine minutes. These distances, though large, are small astronomically speaking. A train travelling at sixty miles an hour would

require over 5,340 years to make the journey, and the fare at three cents per mile would be over 800 million dollars.

The measurement of the distance to the stars with a base line only 8,000 miles long is not feasible, for we find the angle C to be too small to measure. The lines AC and BC are sensibly parallel. We must increase the length of the base line AB. This is done by taking observations six months apart. If the earth is on one side of the sun at the first date, at E in Figure 2, six months later it will be on the opposite side at F, so that the base line is the diameter of the earth's orbit, nearly 200 million miles. One would think that such a base line would be amply sufficient, but the stars are so far away that the angle at C is still very small.

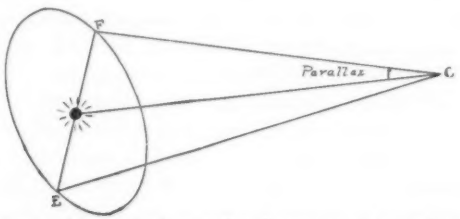

Fig. 2. Astronomer's method of measuring distance to a star, using the diameter of the earth's orbit as a base. EF in figure is known. The angles at the base are measured as in the surveyor's method and the distance to the star follows in the same way.

The accuracy of modern measurements will enable us to obtain accurate results if the angle C is greater than one one-hundredth (0.01) of a second of arc. There are about 2000 stars whose distances have been measured by this method. The closest of all is Proxima Centauri, and for this star the distance is 4.3 light years. This distance which light covers in 4.3 years corresponds to twenty-six million million miles and to a value for half the angle C of 0.76 seconds of arc. Very frequently we quote half the angle C instead of the distance and call it the *parallax*. Thus the parallax of Proxima Centauri is 0.76 seconds. Some other near by stars are:—

Name	Distance in Light Years	Parallax
		"
αCentauri.....	4.3	0.76
Barnard's Star.....	6.1	0.54

Lalande 21185.....	8.3	0.39
Sirius.....	8.8	0.37
Anonymous.....	9.6	0.34
Kapteyn's Star.....	10.3	0.32
τCeti.....	10.3	0.32
Procyon.....	10.4	0.31

The solar system is very isolated in space. From the most remote planet to the sun, as I have said, light travels in a little over four *hours*, while from the nearest star in over four *years*. The surveyor's method can reach out to a distance of three hundred light years.

On any clear moonless night you may be able to see with the naked eye between two and three thousand stars. Counting both hemispheres, there are less than six thousand stars in the entire sky visible to the naked eye. With the aid of a telescope, even a small one, we can see many thousands more. One is amazed at the tremendous number of stars shown in a large telescope. We believe there are 100 million or more within range of the largest instruments, and from all this host we have found less than 3,000 that the surveyor's method has placed at a distance less than three hundred light years. How far are the others away? We measure their distances by other methods.

The next method that I shall speak of depends on a quantity which we call the *absolute magnitude* of a star. The absolute magnitude is a measure of the real brightness. It is defined as the brightness of a star when placed at unit distance from the observer. The term is therefore distinguished from the *apparent* magnitude, which is the actual brightness as seen in the sky. From a comparison of the apparent and absolute magnitudes we can find the distance. The reasonableness of this assertion can be seen at once. Suppose we have a star at any given distance. Remove the star to twice the distance and it will appear four times as faint; remove it to three times the distance and it will be nine times as faint. The apparent brightness of a star depends in a known way on the distance while the real, or absolute, brightness depends on the star itself. We could prove an equation,

$$M = m + 5 + 5 \log \pi.$$

In this equation M is the absolute, or real, brightness, m is the

apparent brightness, measured in the same units as M, and π is half the angle C in our first diagram, or the parallax. There is no difficulty in finding m because we can measure how bright a star appears, and if we could only get M our equation would enable us to compute π and hence the distance.

An instrument which we call the spectrograph enables us to find M. The spectrograph is a photographic instrument and takes a picture of the star's spectrum. In the cut (Plate III) are the spectra of three stars, α Ursae Minoris (Polaris), γ Persei and ξ Ursae Majoris.

α Ursae Minoris is absolutely a very bright star which is very far away and so appears as a star of the second magnitude. γ Persei is a star of medium absolute brightness, while the last is what we call a dwarf star because it does not give very much light. The numbers expressing their absolute magnitudes are -2.2, $+1.0$, $+5.2$, respectively. The spectrum consists of a band running across the page, and crossing the band in each star are fine white lines which we call absorption lines. These are caused by various substances in the stellar atmospheres, and to distinguish one from another they have been given numbers (wave-lengths). We need not stop to inquire the reason for these numbers, although they have an important significance. If the picture were in colours it would be violet at the left and change gradually to blue and blue green at the right. You will notice that the lines 4071, 4077, 4215, 4250, 4270, 4290 are indicated. In α Ursae Minoris, the top spectrum, 4077 is stronger than 4071, while in the dwarf star ξ Ursae Majoris, the latter line is the stronger, while in the second star there is not so much difference between the intensities of the two lines. The same effect is shown by the pair of lines, 4215, 4250 and also by the lines 4270, 4290. The intensity of these lines depends on the absolute magnitude of the stars. The lines 4077, 4215, 4290 are strong in the giants and weak in the dwarfs. The effect was discovered by studying the spectra of stars whose distances, and hence whose absolute magnitudes, were known from measures made by the method previously described. When once the law of variation in line-intensity with absolute brightness is determined, the latter quantity can be found for any star bright enough to have its spectrum photographed. At present the limit

is the ninth or tenth magnitude. Stars of this brightness can be seen in a three-inch telescope. How do we get the distances of fainter stars?

Another method of getting stellar distances depends on the motions of the stars. If we were to take a photograph of the stars to-night and then, two or three hundred years hence, have some one repeat the picture of the same part of the sky, the relative

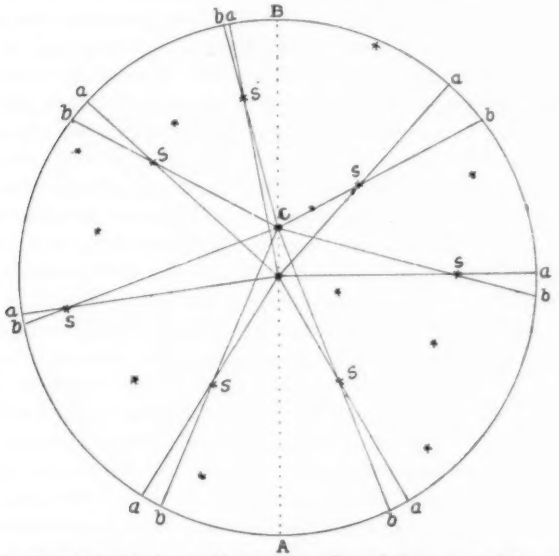

Fig. 3. Herschel's drawing to illustrate the effect of the motion of the sun on the observed positions of the stars. When the sun is at the centre of the circle, the stars are seen at a, a, a, . . . When sun has moved to C, stars move to b, b, b, . . .

positions of the stars on the two plates would not be quite the same. The stars are moving very slowly. We call this motion the *proper motion* of the stars and measure it in seconds of arc per year. Proper motion arises from two causes: first, the sun is moving and this changes the point of observation; second, each star has a motion of its own. The motion of the sun causes all the stars to stream in a definite direction, though not an equal amount, the closer stars moving faster than those more remote. The real

motions of the stars are more or less at random, some moving in one direction and some in another; some rapidly, others slowly. Actual velocities in space may range from nothing to several hundred kilometers per second. In Figure 3, which is a copy of Herschel's original drawing, the effect of the motion of the sun is shown. Suppose the sun is at a point represented by the centre of the circle, the various stars will be seen on the celestial sphere at the points marked *a*, *a*, *a*, etc. When the sun has moved to *C*, the stars will be seen at *b*, *b*, *b*, etc. The stars seem to part from that point in the sky toward which we are moving and to gather together in that point from which we are running away. By examining the proper motions of all the stars, it has been determined that the sun is moving towards a point in the sky whose right ascension is 270 degrees and whose declination is 30 degrees north. This point lies near the bright star, Vega. You must understand that this apparently simple theory is complicated, but not rendered less valuable, by each star having a motion of its own, which is superimposed upon the motion caused by the sun's velocity.

In addition to the proper motion of the stars, which is a motion on the celestial sphere, the stars are moving toward or away from the sun. This component of motion does not affect the apparent position in the sky, but we know it must be there and the spectroscope enables us to measure it. We call this motion *radial velocity* and reckon it in kilometres per second. The observed radial velocity of a star depends on the speed of the sun as well as on the star's own motion. Suppose we take the radial velocities of one hundred stars, all in that part of the sky toward which the sun is moving. We should expect the average algebraic value of the velocity of these stars to give the velocity of the sun. We have a right to assume that among one hundred stars as many will have motions away from as toward the observer and that therefore the average will make the stars' motion vanish approximately.

Some may think that we are making a bold assumption here and that our results will not be accurate, but chance can be reduced to a law just as truly as other phenomena. If I were to ask you how you know the sun will rise to-morrow morning the answer must reduce to this: It has risen in its appointed place for a good many mornings and the chances are that it will come around

to-morrow again. If I were to wager that the names of all the people in a large audience began with the letter A, I would not have much chance of winning the wager. We could tell pretty well how many names would begin with A, how many with B, and so forth. Experience has taught us that improbable events seldom happen and that when a certain condition is very probable we may accept it as the true state of affairs. We know of no reason why the stars should favour one direction of motion in space rather than another, and so assume that as many come toward us as move away from us. If we admitted that the stars on the average were approaching us this would be equivalent to a general contraction of the universe. The opposite assumption would be the same as a general expansion. Both assumptions are unlikely. It has been found then from the radial velocities of the stars that the speed of the sun's motion toward Vega is about 12 miles per second. When once this has been found we can compute how fast any star is either approaching toward or receding from the sun. The radial velocity tells us nothing about the velocity at right angles to the line to the star which is the component that contributes to the observed proper motion.

Let us consider a hypothetical case, in which the radial velocity is zero, and also let us suppose that the particular star is in that part of the sky which is not affected by the sun's motion, namely, in the constellation of Lyra. We could calculate how far the star was away if we only knew its velocity at right angles to the observer in kilometres per second, for its velocity would give us the distance moved in the course of a year, while the proper motion would tell us the angle this distance subtends at the observer. The distance to the star would be given by the simple relation

$$\pi = 4.74\mu / V$$

where π is the parallax, μ the proper motion and V the velocity.

Now let us examine an actual case. In Figure 4(a) let O be the observer and S the star at any time. One year later the star may have moved to S' *relative* to the sun. The angle $S'OR$ is the proper motion and SR the radial motion relative to the sun in one year, which, divided by the number of seconds in a year, gives the velocity. Figure 4(b) represents the proper motion $S'R$ as seen on

the celestial sphere. Resolve it into two components, one along the direction to the solar apex and one at right angles to this. We call these the v and τ components, respectively. The v component arises from the star's motion and from the sun's, but the τ component is due to the star's motion alone. If we knew the velocity in kilometres per second which caused the observed τ component we would have our hypothetical case again. Suppose we have a number of stars, all in the same region of the sky as

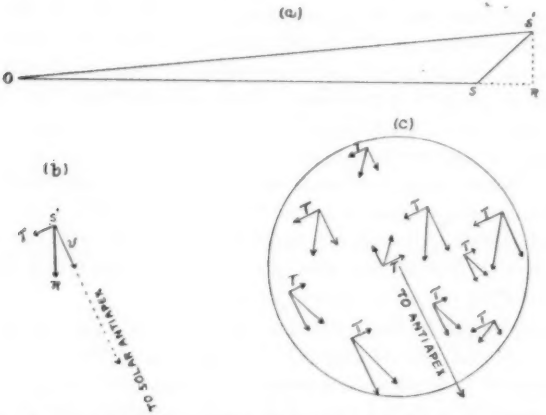

Fig. 4. Diagrams to explain methods of getting mean distances of groups of stars from the observed proper motions. For explanation see text.

in Figure 4(c), and we draw their proper motions and τ and v components. We should expect that some of the τ components would fall to the left, some to the right of the v components which, on the average, would point to the sun's anti-apex. Since the τ component is caused by the velocity of the star in a particular direction in space, we can assume that its average value arises from a velocity which is numerically equal to the average radial velocity for these stars. The mean distances will be given by

$$\bar{\pi} = 4.74\bar{\tau}/\bar{V}$$

where $\bar{\pi}$ is the mean parallax of the group, $\bar{\tau}$ the mean value of the τ components and $\bar{V}$ the mean radial velocity. The method is

most accurate when the group contains a great number of stars, but even with only a dozen stars in the group the error in the mean parallax deduced should not be over 15 per cent. The method is available for all stars for which we have proper motions and radial velocities and becomes ever more valuable with the accumulation of astronomical data. Very faint stars have not as yet had either their proper motions or radial velocities determined. We estimate the distances of the latter by a fourth method which is called "counts of stars."

In order to explain the method I must say a little more about the term *stellar magnitude*. You can see in the sky, on any clear night, stars of various degrees of brightness. We speak of the brightest stars as being of the first magnitude; stars fainter than these are said to be of the second magnitude, and stars which are just at the limit of vision are of the sixth magnitude. Thus the term *magnitude* or *apparent magnitude* refers to brightness only. Each magnitude is so many times brighter than the next, and the ratio is such that when multiplied by itself five times the result is 100. The ratio is therefore the fifth root of 100 or 2.512.

A star owes its apparent magnitude to its actual brightness and its distance. If it is a very faint star it may be either a small star at a moderate distance or it may be very far away but of fair size. The fainter stars should, on the average, be farther away than the brighter. Since light falls off as the square of the distance, the sixth magnitude stars should be about ten times as far away as first magnitude ones.

Eleventh magnitude stars should be ten times as far away as sixth magnitude ones; sixteenth magnitude, one hundred times, and twenty-first magnitude, one thousand times. All the bright stars, or at least the great majority, have had their distances determined by the means I have already explained, and the sixth magnitude stars have an average distance of two hundred light years. This would make the average distance of stars of the twenty-first magnitude nearly 200,000 light years. However, we are making a rather serious mistake in this estimate, for we are neglecting the fact that among the very faint stars there is an ever increasing proportion of really faint stars. The effect of neglecting this factor is to make the figure 200,000 much too large. The average twenty-first magnitude star is less distant than this.

We ask ourselves, in view of these great distances, whether the stars go on for ever or whether they come to an end? Counts of stars enable us to answer this question also. Suppose the stars extend indefinitely and that they are uniformly distributed in space. Draw a sphere of unit radius about the sun and let it contain n stars. A sphere of two units radius should contain $8n$ stars, the volume of a sphere increasing as the cube of the radius. The geometry of the problem will tell you that there are about four times as many stars of second magnitude as there are of first magnitude, four times as many of third as there are of second. We call *four* the theoretical star ratio, more exactly it is 3.98. We

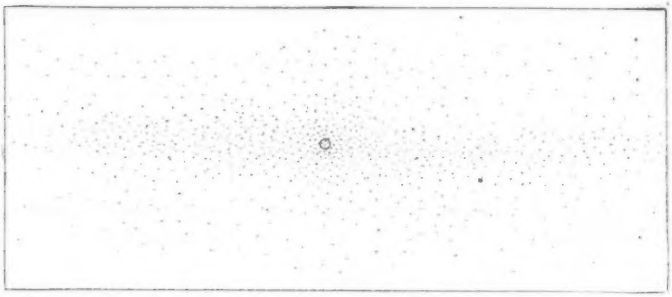

Fig. 5. Kapteyn's conception of the universe. Each dot in the diagram represents a star. Our sun is near the centre of the figure and the stars thin out in all directions, forming what is known as an ellipsoid of revolution. The diagram is a cross section of the ellipsoid at right angles to the plane of the Milky Way.

find that the theoretical star ratio is maintained fairly well for the bright stars, but grows less and less as we count fainter stars. This means that the stars thin out as we proceed to great distances from the sun. Counts of stars in all parts of the sky have led us to a conception of the universe as shown in Figure 5. This picture represents the stellar system as conceived by Kapteyn. According to this astronomer, who spent practically his whole life investigating the problem, the Galaxy, or Milky Way, is a vast cluster of stars in the form of a flattened ellipsoid of revolution. The stars are most numerous near the centre and grow less in number toward the boundaries. At a distance of 1,800 light years in a direction at right angles to the Milky Way there are only one-tenth as many

stars per unit volume as near the centre. In the plane of the Milky Way we have to go outward about 9,000 light years before the number of stars diminishes to the same extent. The corresponding distances for a decrease in the number of stars to one-hundredth the number at the centre are 5,500 and 28,000 light years. The total number of stars, including those scattered at great distances, which may extend to 200,000 light years, is given as 47,000 million.

We see other objects in the sky besides the stars; we see gaseous nebulae, dark nebulae, star clusters and spirals. Where do these objects fit into the universe of stars? The distances of the first two classes of objects place them within the system of stars, while the last two classes are at greater distances. I shall first discuss the ways of getting the position of the gaseous and dark nebulae, and later treat the star clusters and spirals separately. Two photographs typical of the gaseous nebulae are reproduced in Plates IV, V.

The gaseous nebulae, so-called because the spectroscope tells us that they consist of very tenuous gas, are divided into two classes, the planetary and irregular varieties. Plate IV, the ring nebula in Lyra, is a planetary nebula. Nebulae of this type are always of symmetrical form and seem to consist of a gas shell surrounding a central star. In the ring nebulae only the outer parts of the shell are bright enough to be seen for near the edge we are looking through greater depths of material. The distance of the nebula is the same as the distance of the central star. Direct parallax determinations have been made of the central star for most of the objects of this class, and we find that they are only a few hundred light years distant.

Plate V is a filamentary nebula in the constellation of Cygnus. You will notice that the nebula is fairly well defined on the one edge and fades gradually on the other, also that the stars are much more numerous on the one side than the other. The explanation of this is that the nebula lies within our system of stars, and on the one side there is considerable dark obscuring matter which cuts off light from the stars behind, By counting the stars of various magnitudes we are able to tell just about at what magnitude the stars begin to be obscured and hence estimate the approximate distance of the object. In the "Dark

Bay" nebula (see this *Journal*, Vol. 15, Plate III, 1921), the existence of dark nebulosity is clearly shown and the appearance here suggests that the dark matter is being illuminated from the one side, presumably by the light from the near-by bright stars. In all cases the distances of the gaseous nebulae are less than the extent of the visible stars. It is a remarkable fact that all these objects lie in the plane of the Milky Way, and the extent of the nebulosity in this zone is so great that we believe that, viewed from outside, our system of stars would be seen as a huge disk with a dark streak running across it. The consideration of the gaseous nebulae has not led us to any enlargement of the confines of the universe.

We have assumed that the stars are moving at random and are uniformly scattered, but while this is in general true there are groups of stars which are obviously associated, such as the Pleiades and the Hyades and other groups not so conspicuous. We call these *star-clusters* and they may be divided into two classes, open and globular. In the open clusters a number of stars are seen to be associated, but they are reasonably removed one from another, so that in a telescope they scarcely look like clusters at all. The stars in a globular cluster are closely packed. The number of open clusters is about two hundred and there are about seventy globular clusters. The distances of the open clusters is not great, and they may be considered as composed of stars which are part of our universe though their existence must have an important bearing on theories of origin. The distance of the globular clusters is much greater and until recently defied measurement. A picture of one of the globular clusters, the Great Cluster in Hercules, is shown in Plate VI. The number of stars in these clusters can only be estimated, because on the long-exposure photographs necessary to show the faintest stars, the centre of the cluster becomes burned out and individual stars are obliterated. There must be 50,000 stars at least in the cluster shown.

We owe our knowledge of the distances of these very interesting objects largely to the work of Shapley, now director of the Harvard College Observatory. The proper motions are too small to have been determined in the short time the clusters have been under observation, and the spectra of individual stars have

not been obtained. The stars are mostly fainter than the twelfth magnitude. A new method of attack was discovered through the observation of a certain class of variable stars, called Cepheid variables. Like the spectroscopic method, it makes use of the absolute magnitudes in conjunction with the apparent magnitudes. Stars of the Cepheid variable class are found both among the stars in general and in the clusters. From a discussion of the variables found among the stars in general and in an object of great interest in the southern hemisphere, called the Magellanic Cloud, Shapley was able to show that the period of light variation in this class of star was directly related to the absolute magnitude, and that once the period was known the absolute magnitude could be calculated. We do not know why this should be so but simply that it is a fact. The periods of the Cepheid variables have been determined in the brighter clusters. This tells us their absolute magnitudes and then, making use of the formula $M = m + 5 + 5 \log \pi$, we compute the parallax. A somewhat different method has been extended to the fainter clusters so that the distances of these too are known.

The nearest cluster, ω Centauri, is in the southern hemisphere; it is 21,000 light years away. The most remote is over 200,000 light years distant. The dimensions of the globular clusters, though they look small, are correspondingly large. Most of them are about 100 light years in diameter. The number of stars per unit volume of space is much greater in the clusters than in the stars in general, probably two or three hundred times as great, but even so the average distance apart would be something like fifty million million miles, and there would be plenty of space to move about within the cluster without fear of collisions. The globular clusters, like the open clusters and the gaseous nebulae, are all found in the neighbourhood of the Milky Way, but there is this difference that, whereas the gaseous nebulae and the dark nebulae are most numerous in the exact plane, the globular clusters are not found there but near to it and on each side. Astronomers incline to the view that the distance and faintness of the clusters renders those that lie exactly in the plane invisible, they being hidden by the gaseous material of the Galaxy.

Besides the nebulae which appear in the Milky Way there are many others found in large numbers in a direction at right angles

to its plane. They have been called nebulae because until recently they appeared as hazy patches of light very similar to those located in the Galaxy. In late years some of them have in part been resolved into stars, but even before this the spectroscope had decided that they were not gaseous, but composed of stars. These objects are very numerous. It is estimated that between two and three hundred thousand are within reach of our telescopes. Mostly they are very small and faint, but the one which is largest and brightest, the Great Nebula in Andromeda, is visible to the naked eye. Over ninety per cent. of the extra-galactic nebulae, as they are called, are regular in outline, either spherical or oval, most frequently having some kind of spiral structure. The remainder of the extra-galactic nebulae are few in number, and some of the brighter ones can be partially resolved into stars, showing that they too are huge star clouds.

We might surmise that these objects are very remote from the difficulty we have in resolving them into stars, but their exact distances defied measurement until recently. We may suppose that the nebula in Andromeda, being the largest and brightest, is among the closest of the class, and more work has been done on it than on the others. Its distance has been measured.

There are two ways by which the distance of spiral nebulae are determined. The first of these makes use of new, or temporary, stars appearing within the nebula. The name *new* or *temporary* is applied to a star which unexpectedly increases its light many thousand-fold. The cause of this great increase in luminosity has never been satisfactorily explained, but many of the characteristics of temporary stars have been investigated. A temporary star of the seventh magnitude at maximum brightness appeared in 1885 in the Andromeda nebula. It was uncertain whether the star was at the same distance as the nebula, or whether merely in the same line. Continuous study of the nebula has discovered over sixty new stars appearing within the boundary of the nebula and none without, and we may conclude that the temporary stars appearing within the boundary of the object are actually at the same distance and associated with it. Now from time to time new stars are discovered in the constellations and these usually rise to be brilliant stars. We can get a fair estimate of the distance of the latter,

and, assuming that the average real brightness of the nebular nova is comparable to the others, we can compute the distance of the former.

A more direct and trustworthy method is afforded by the study of variable stars within the nebula. Recent photographs of the outer parts of the nebula, made with the 100-in. telescope at the Mount Wilson Observatory, have resolved the nebulosity into very faint stars. Among these stars Cepheid variables have been discovered, with periods ranging from eighteen to fifty days. You will remember that when the period of a Cepheid variable is known we can compute the absolute brightness, and then a comparison with the apparent brightness gives the distance. The distance to the Andromeda nebula comes out a little less than 900,000 light years.

The confines of the visible universe as known at the present time reach to the spiral nebulae. Those whose distances have been measured are of the order of one million light years from us. We should expect that the fainter spiral nebulae are much farther away still, perhaps hundreds of millions of light years, but as yet we can hardly say that we have measured their distances.

University of Toronto.

A DOUBLE-LINED CLASS B SPECTROSCOPIC BINARY SYSTEM

By S. N. Hill

THE star H.D. 214240 is situated at R.A. 22h 31.8m, Dec. +49° 33′, and is of visual magnitude 6.20, while the H.D. Catalogue gives the spectral type of this star as B3. It is one of the stars in the B-type programme under observation at Victoria. The binary nature of this star, not hitherto announced, was discovered by the writer.

Table I—Lines Measured in the Spectra

Primary (B2.5)	Secondary (B8)	"Stationary" Ca+
λAtom	λAtom	λAtom
3964 He	3964 He	3834 Ca+(K)
3970 Hε		3968 Ca+(H)
4009 He	4009 He	
4026 He	4026 He	
4070 H	4102 Hδ	
4072 H	4121 He	
4075 H	4128 Si II	
4102 Hδ	4131 Si II	
4121 He	4144 He	
4144 He	4267 C+	
4267 C+	4340 Hγ	
4340 Hγ	4388 He	
4388 He	4471 He	
4471 He	4481 Mg+	
4481 Mg+		
4713 He		
4861 Hβ		
4922 He		

Thirty-two spectra, obtained by different members of the observing staff, were employed in this orbit. After the approximate period of 10.91 days was selected, these were grouped into twenty-

one normal places. In the least-squares correction to the elements the equation of Lehmann-Filhés was used, involving six unknowns. The grouping of the normal equations from the observations was arranged so that a normal place included only a small number of revolutions, and thus the result is almost as rigid as if the individual observations had been treated separately. The normal places were weighted according to the number of plates in the normal place, each single plate being given weight unity.

As mentioned above, the H.D. Catalogue gave the spectral type of this star as B3, but as the oxygen triplet λλ4070, 4072 and 4075 was present on some of the plates, although showing faintly, the type of the primary seems somewhat earlier than B3 and has been classified as B2.5.

The lines measured in the spectra are shown in Table I.

The relative intensity of the spectral lines of the primary as compared with those of the secondary is about 3 to 1. Only at the nodes, where the separation is about 200 km. could the secondary be measured with any degree of accuracy. The Si II lines λλ4128 and 4131 were measured on several plates at the nodes, and the velocities of these lines agree well with those of the secondary spectrum which indicates that its type is B5 or later. Again the relative intensity of the helium line λ4471 to the mg. line λ4481 was used as a criterion of the type and a careful comparison of these lines on the micrometer engine showed them on the whole to be equal. In view of this, the secondary spectrum has been classified as B8. The lines in the spectrum are weak and difficult of measurement. The probable error of a single plate of weight unity is ±9.2 km. per second, while that of the primary, where the lines are fair, is ±3.2 km. per second. On account of the poor equality of the lines of the secondary spectrum the writer did not include it in the least-squares solution of the primary. However, corrections for K2 were obtained by accepting the elements from the primary solution and obtaining by least-squares the most probable correction for K2. The solution of the primary reduced Σpvv from 515 to 398, a reduction of approximately 23 per cent.

Figure 1 shows the individual velocities of the primary and secondary spectrum and those of the enhanced calcium lines plotted on the final velocity curve.

The mean velocity of the H and K lines of ionized calcium is -18.9 ± 0.3 km. per second, while the probable error of a measure is ± 1.6 km. The lines are good and, as the velocity indicates, do not oscillate with the star as shown on the figure. The component of the solar motion in the direction of this star is -11.8 km. per second, giving a residual velocity of -7.1 km. per second for the calcium cloud. Such differences between the velocity of calcium and the component of the solar motion are not unusual among the O- and early B-type stars as shown by Dr. Plaskett.[1]

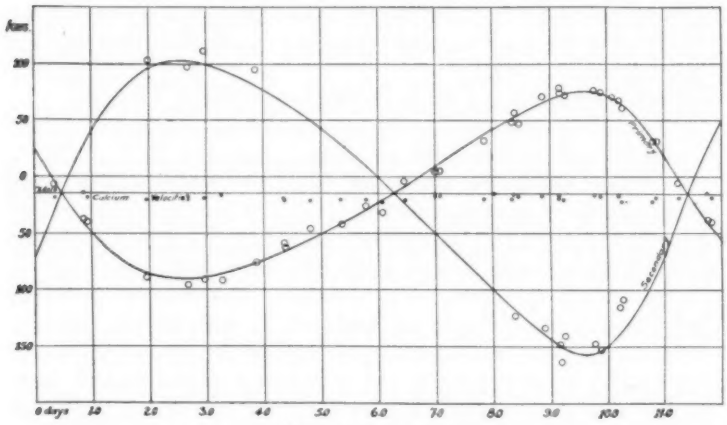

Fig 1—Velocity Curves of H.D. 214240.

The values of the preliminary and final elements are given in Table II.

Considering the spectral type of H.D. 214240 as B2.5 for the primary and interpolating from Fowler and Milne's[2] scale, a temperature of 17,500° K. has been assigned to it. The spectral lines of the brighter component of the star under discussion have been compared with those of u Herculis, a B3 star whose photometric orbit[3] has been obtained and whose density is given as 0.097 for the primary. The spectra of the primaries of these two stars are very similar in appearance and the stars are not unlike in mass, u Herculis being 7.5 times the mass of the sun while the

minimum mass of H.D. 214240 is 6.01 times the sun, while if the inclination is assumed to be the average value the mass would be 9.25 times the sun. Considering a temperature of 17,500° K mentioned above a surface brightness by Hertzsprung's method[4] of −3.24 magnitudes, 19.76 times the sun, has been computed. On account of the high eccentricity of H.D. 214240, viz., 0.253, the star has probably had a considerable advance in its evolutionary stage and it seems reasonable to assume that its density is of the order 0.10. With surface brightness of −3.24 magnitudes compared with the sun and a minimum mass of 6.01 times the sun, the

TABLE II—ELEMENTS OF H.D. 214240

Element	Preliminary	Final
P = Period	10.91 days	10.9114 ±0.00126 days
e = Eccentricity	0.25	0.253 ±0.012
K_1 = Semi-amp. prim.	85 km.	83.27 ±0.93 km.
K_2 = Semi-amp. sec.	124 km.	129.44 ±3.59 km.
γ = Velocity of system.	−15.12	−15.28 ±0.70 km.
ω_1 = Longitude of apse.	65°	67°.54 ±2°.97
ω_2 = Longitude of apse.	245°	247°.54 ±2°.97
T = Time of periastron.	J.D. 2,424,340.478	J.D. 2,424,340.5415 ±0.0937
$a_1 \sin i$ = Semi axis maj. prim.		12,088,000 km.
$a_2 \sin i$ = Semi axis maj. sec.		18,789,000 km.
$m_1 \sin^3 i$ = Mass primary		6.01⊙
$m_2 \sin^3 i$ = Mass secondary		3.87⊙

absolute magnitude is calculated as −1.86 for a density of 0.05, −1.35 for a density of 0.10 and −1.06 for a density of 0.15. The difference of magnitude between a star of mass 6.01 and one of 3.87 times the sun by Eddington's method[5] is 0.71 magnitudes. We have, therefore, two stars of a total visual magnitude of 6.20 differing by 0.71 magnitudes from which is obtained a magnitude of 6.65 for the brighter and 7.36 for the fainter.

By the use of the fundamental equation showing the relation between absolute and apparent magnitude

$$M = m + 5 + 5 \log \pi$$

the parallax is computed as 0".00251 or 1,300 light years. However, if we consider the average inclination of the orbital plane for

H.D. 214240, $\sin^3 i = 0.65$, the masses become 9.25 and 5.95 times the sun, which, for the density, temperature and surface brightness mentioned above, give a parallax of 0″.00217 or 1,500 light years. So the star under discussion appears to be at least 1,300 light years distant and in all probability nearer 1,500.

On the relationship between mass and luminosity by Eddington,[5] after applying the temperature term $-2 \log_{10} Te/5200$, the bolometric absolute magnitude for H.D. 214240 is computed as -2.34 and, after applying the correction for visual magnitudes of $+1.50$, the visual magnitude becomes -0.84 against -1.35 by the luminosity method. The visual magnitude of -0.84 corresponds to a density of 0.2. From the above assumptions and computations, together with the discussion on H.D. 191201[6] and some recent work on H.D. 1337,[7] both made at this Observatory, it would appear that Eddington's theory gives a magnitude somewhat too small for the higher temperature stars, such as the one discussed in this paper. Complete details will appear in a publication of the Dominion Astrophysical Observatory now in press.

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CANADA'S GROWING PAINS

By Ernest A. Hodgson

Broadcast from Station CNRO (Ottawa), February 7, 1927.

HEALTHY growing children sometimes complain of sharp stinging pains, which, for the moment, cause a convulsive start, but which are as quickly gone. We encourage them by the statement that these are "growing pains"—the evidence of the rapid rate at which they are attaining their pet ambition of growing up. With increasing age and stature the pains gradually disappear, as a rule.

Politically, Canada is surely young enough to have growing pains. It would be interesting to consider the various ways in which she suffers through her rapid political and economic growth. However, we are not concerned with this for the moment.

Geologically, Canada is very old. We shall not be so impolite as to pry into the matter. The lady is rather reticent on the subject of her age. Certain it is, she suffers fewer twinges due to growth than do other and younger countries. On the other hand, we shall find that she does have an occasional sharp reaction which indicates that she is not yet too old to present evidences of growth, or, at any rate, of change. We shall be gallant enough to refer to these as "growing pains" rather than rheumatism. How shall we begin a diagnosis?

The doctor studies your condition by means of a stethescope, making use of the sound waves which have originated within your body, in heart or lungs; or he secures a photograph, recording the waves of light which have traversed your body, and which originated in the X-ray of the laboratory. The seismologist studies the internal structure of the world by means of a seismograph, making use of those waves or vibrations which have passed through the earth, and around its surface, and which originated in an earthquake.

For such a study of the deep recesses of our planet, we require the records of earthquakes which have originated at distances greater than 6000 miles from the seismograph. The instruments at the Dominion Observatory, at Ottawa, are very conveniently situated for an investigation of the internal structure of the earth.

Earthquakes frequently occur in the East Indies, in the Philippines, in Japan, in the Aleutian islands, and in Alaska—that is to say, all about the western and northern shores of the Pacific. Now, if you were to start off, in an aeroplane, in a direction north-west as you left Ottawa, and were to fly, from Ottawa to Java, by the shortest possible route, such as would be defined by a string tightly stretched, and joining those two places on a globe, you would pass in turn over Alaska, the Aleutian islands, Japan, the Philippines, and finally, Java. Alaska is about 3000 miles away on such a course; northern Japan 6000 miles; and Java nearly 10,000.

We have here, then, a line of potential earthquake positions, situated at varying distances from Ottawa. As each occurs, a study of the records at the various seismological observatories will enable us to determine its origin or epicentre, and also its time of occurrence. A series of earthquakes having been registered and located as on this Ottawa-Java belt we can, from the records registered here, investigate earthquake tremors which have arrived from the north-west in every case but from distances varying from 3000 miles in Alaska to 10,000 miles in Java.

When you go on a journey you dig down into your pockets to foot the bills. The farther you go, the deeper you dig. Earthquakes are subject to a law which is somewhat similar, the greater the distance travelled from epicentre to station, the deeper will be the path traversed by the waves in their journey. Thus, in studying these records of earthquake waves arriving from various distances, we are securing information as to conditions at various depths within the earth along this seismic arc.

It is found that, as the distance from the station to the epicentre increases, the speed of propagation of the first sharp wave increases. A preliminary wave requires about six minutes to cover the 3000 miles from Alaska to Ottawa. A similar wave, originating in northern Japan will arrive in nine minutes and a half. The distance is double but the time required is less than double by a good margin.

A close study of the variation of the velocity with the distance, which really means a variation of the velocity with the depth traversed, reveals the fact that there are sharp breaks in the rate of change of velocity. This is interpreted as indicating surfaces of discontinuity between various layers in the interior of the earth.

The records at Ottawa confirm the investigations which have been made so far, in this direction.

We may sum up the deductions. At the centre of the earth there is, we believe, a heavy metallic core, made up probably of nickel and iron, whose radius is about five-ninths that of the entire earth. Surrounding this is a so-called "transition layer", made up of three concentric spherical shells, in all, about a thousand miles in thickness. About this again is a rock mantle, a spherical shell of rock, heavier than granite, of a thickness somewhat less than that of the transition layer. The outer surface of this rock mantle is still very hot, and, were it not for the pressure of the remaining forty-odd miles of lighter granitic rocks, would be fluid. On this layer, the outer crust of the earth floats, as it were, partly immersed, like an iceberg in the ocean.

It is believed that, if you could get down to the bottom of this outer crust, to the top surface of the rock mantle, you would find conditions there the same at all points on the globe, and if you were to dig into the earth beginning at any point on the surface and proceeding toward the centre, you would find conditions to depend only on the depth below the surface of the rock mantle, and not on the position on the surface from which you began. The records of seismographs strongly support this belief.

An important conclusion results. The geological differences to be found in the various countries of the world, all lie within this upper forty-mile crust or skin. Thus we find a new application of Kipling's remark, that "Judy O'Grady and the Colonel's lady are sisters under the skin". For Canada, and China for example, differ geologically only to the depth of this relatively thin crust. Now all Canada's growing pains are located within this upper layer. It is really her skin that gives the lady trouble as she ceases to record her birthdays.

Our diagnosis then, up to this point, reveals the fact that the seat of these growing pains is in the upper forty miles. Can the same instruments be used to study the skin, as were used in the case of the body? A new type of seismograph *has* been devised for this purpose. To make use of it we must choose an area and make a detailed study of its earthquakes—for Canada's growing pains are really growing strains; when these strains are relieved we have earthquakes. Canada is not subject to severe earthquakes, but

many scientific and economic returns may be expected from a study of these relatively minor shocks which occur from time to time in both eastern and western Canada.

The use of this new type instrument requires elaborate precautions to maintain identical time at three different seismograph stations. Suppose we choose our area for investigation. We then build a special underground vault at each corner of an equilateral triangle whose sides are, say, a hundred miles long in each case, and whose position roughly covers the area to be studied. We inter-connect the vaults by wire so that a single source of alternating electric current may drive all nine recording drums (three at each station), at the same rate, and so that time may be automatically recorded by one central clock, on all the seismograms. A study of the relative times of arrival of the phases of the microtremors recorded will indicate the positions of their sources, and the initial times of the shocks. We can thus determine how many occur, and their relative intensities. In time we can deduce their depths of origin, within the crust, and eventually the thickness of that crust, for some of the waves reaching the seismograph will go down to the top of the rock mantle and be there reflected before reaching the seismograph. We can, thus, in time, know all about the activity of the seismic centres within or near the triangular net of seismographs.

If these seismic centres were known, we would do well to avoid them as sites for elaborate and costly installations or heavy buildings. A similar study of conditions in California has been so successful that business men there are financing its further prosecution. An investigation of this kind is now proposed for the Ozark mountain region of the central United States.

Instruments for a preliminary investigation are being secured in eastern Canada. Canada's earthquakes are not at all serious but they are well worth studying nevertheless. The case is an interesting one scientifically. All we know now is that certain areas are subject to these earthquakes, and that relatively severe shocks occur at somewhat irregular intervals. We believe that a study of the little twinges for many years would be repaid many times over in our added knowledge of the laws governing them, and in our preparedness for those emergencies of the inevitable, though widely separated, acute attacks of Canada's Growing Pains.

Dominion Observatory, Ottawa, Canada.

THE PLANET VENUS:

A Concise Tabulation of Many Items of Interest to the Amateur.

By W. G. Colgrove

Name—Among the Greeks Venus had two names,—Phosphorus or Lucifer as morning star, Hesperus as evening star. For many years and in many lands it has been known as the Shepherd's Star. By some it has been thought to be the Star of Bethlehem because at certain times it is a brilliant object in the December sky.

Myth—Venus was the daughter of Jupiter and Dione and was given by her father to Vulcan as his wife. She was the goddess of love and beauty. Her little son Cupid became the god of love. The Greeks called him Eros.

Symbol—A circle with a handle ♀ representing the mirror which Venus constantly used to behold her beauty.

Sound—In the Music of the Spheres the ancient poets assigned to Venus the rôle of Alto.

Colour—A glistening yellowish white—so dazzling that it is very difficult to observe the disc with any degree of satisfaction.

Markings—In spite of the glare some astronomers have seen ill-defined markings, which, however, were not permanent, and drawings by different astronomers did not agree.

Stellar Magnitude—This varies from –3 to –4 according to its distance from us and its phase. Its maximum brightness occurs about 36 days before and after inferior conjunction when its phase is like that of the moon five days old.

Angular Diameter—This also varies with the distance—the greatest, mean and least being 66″, 38″, 10″ of arc.

Linear Diameter—The actual mean diameter is about 7700 miles.

Circumference—By multiplying by 3.1416 we get 24,200 miles.

Area of Surface—By squaring the diameter and multiplying it by 3.1416 we have a surface of 186,290,000 square miles—about .95 of earth.

Volume—By cubing the diameter and multiplying by .5236 we find it to be 235,008,958,800 cubic miles—about .92 of earth.

Mass—In cases like Venus where there is no satellite it must be determined from the perturbations caused by the earth and

Mercury when near to Venus; also from the attraction of an occasional comet that passes by.

Density—Water being the unit of density, Venus is 4.86.

Gravity—.85 of earth. A boy weighing 100 pounds here would weigh only 85 pounds on Venus.

Rotation Period—Not yet fully determined. Some earlier astronomers from a study of the faint markings on the surface said it rotated like the earth in about 24 hours. Others say it is like Mercury turning the same face always to the sun. Still others claim that it rotates in about 3 days with its axis in the same plane as its orbit; still others, 4 or 5 weeks. When doctors disagree let some amateur decide.

Equatorial Velocity—This must wait until someone discovers the rotation period.

Distance from Sun—Mean 67,200,000 miles. The orbit is almost a circle.

Distance from Earth—It varies from 25,700,000 miles at inferior conjunction, to 160,100,000 miles at superior conjunction. It is, therefore, about six times as far from us at superior as at inferior conjunction.

Diameter of Orbit—Mean 134,400,000 miles, being double its mean distance from the sun.

Circumference of Orbit—421,000,000 miles, being the total distance covered by the planet in each revolution around the sun.

Revolution (Sidereal Period)—225 of our days, or nearly 7½ months. Durnig this time Venus returns to the same point in the sky, as seen from the sun. It makes almost 13 revolutions to 8 by our earth.

Revolution (Synodic Period)—584 of our days, or 1 year and 7 months. During this time Venus travels from one inferior conjunction to another, or from one superior conjunction to the next.

Velocity in Orbit—22 miles a sec., 79,200 miles an hr., 1,900,800 miles a day.

Arc of Retrograde—16 degrees. This is due to the combined motions of the earth and the planet.

Eccentricity of Orbit—.007, or the centre of the orbit is only 470,000 miles from the focus wherein is the sun.

Light and Heat—1.91 times the amount received by the earth.

The temperature would be tropical were it not for the dense, cloud-laden atmosphere which surrounds Venus.

Atmosphere—Possibly twice as dense as ours. Unlike some other planets Venus has surface gravity enough to retain her atmosphere, and this is proved during transits across the sun when a distinct fringe of light is visible around the disc. This is also apparent at inferior conjunction when the illuminated edge projects beyond the horns of the crescent.

Inclination of Axis to Orbit—This, like the rotation period, is still in doubt, the estimates being all the way from 0 to 90 degrees.

Inclination of Orbit to Ecliptic—3 degrees 24 minutes.

Pole Star—Through lack of knowledge of the inclination of the axis it is as yet impossible to tell what star commands the pole.

Phases—The phases are similar to those of the moon. When Venus is at inferior conjunction her dark side is toward us and the phase is new, when at greatest elongation the phase is quarter, when at superior conjunction the phase is full.

Longitude of Node—75 degrees 55 minutes. The ascending and the descending nodes are the points on the ecliptic where the planet's orbital plane cuts the ecliptic.

Conjunction—This occurs twice in each synodic revolution of an inferior planet; with Venus twice in 584 days. They are known as inferior when between us and the sun, and superior when on the opposite side of the sun from us. From inferior to superior conjunction she is a morning star; from superior to inferior conjunction an evening star.

Transits—Planetary transits occur only with the two inferior planets because they alone can pass between us and the sun. A transit of Venus occurs at inferior conjunction only when it is near one of the nodes in June or December, and transits are rare because of the inclination of the orbit. The last occurred on December 6, 1882, the next will be on June 8, 2004, and be followed by another on June 6, 2012.

Satellites—None have yet been discovered. If one should be found the name Cupid might be appropriate.

Life—As in the case of Mars so with Venus the problem of life is still unsolved.

Cedar Springs, Ont.

THE EXPERIMENT OF MILLER AND THE HYPOTHESIS OF THE DRAGGING ALONG OF THE ETHER

By H. MINEUR in *L'Astronomie.**

DURING almost twenty years two new conceptions have thrown physics into confusion: the theory of relativity and the theory of quanta. The first has met with lively resistance in the world of science; perhaps the relativist revolution advanced too quickly; it upset what was believed solidly founded—the ideas regarding space and time; it demanded of the man of science to clear the board of conceptions amid which his spirit had always lived. Relativity was born of the experiment of Michelson (1887); this experiment, repeated in 1925 under new conditions by Miller, has given a result altogether different from that of Michelson. Will relativity fall? Will it surmount the obstacle?

We set forth on broad lines the debate which has arisen since the memoir of Miller appeared.

The Ether Considered as a Material Fluid.

The investigations of Huygens and of Fresnel have established the nature of luminous phenomena; light is composed of transverse vibrations; this leads us to admit the existence of a vibrating medium,—the ether; light is analogous to those waves which traverse the surface of water into which a stone is thrown. Light traverses empty space and transparent bodies,—the ether must therefore exist everywhere; the notion of ether is almost confounded with that of space: "The ether has been invented for the purpose of giving a subject to the verb, undulate".

Is this ether immovable? Is it capable of movement like a liquid or a gas? Stokes[1] offered (1845) the following hypothesis: the ether is fixed in interstellar space but the celestial bodies drag along in their movement the part of the ether which is found in their immediate neighborhood, as a train in motion carries along with it a portion of the atmosphere.

*Translated by A. F. Miller.

We must avoid confounding this hypothesis of "the partial dragging along of the ether" with a theory which bears a similar name—Fresnel's theory of the drift of the ether waves verified by many experiments. The limit of this note does not permit us to dwell on this point: we shall return to it at another time.

The Experiment of Michelson and Morley.

Michelson had the following idea: if the ether exists we might determine the velocity of the earth in relation to that medium as a mariner determines the speed of his vessel as referred to the sea. Needless to say that the experiment designed by Michelson in no way resembles towing a log with a rotating mechanism; it is based on the idea following:—

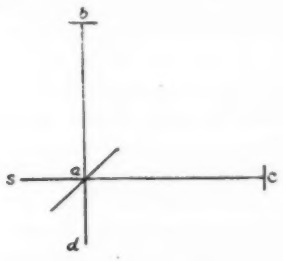

Fig. 1. Source stationary.

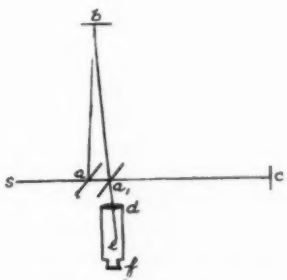

Fig. 2. Source moving.

Diagrams illustrating the path of the light.

Let *sc* (Fig. 1) be a segment of a straight line of invariable length; a ray of light goes from *s* to *c*, is reflected at *c* by a mirror and returns to *s* at the end of time *t*. The ray of light traverses the ether with the velocity *c* of light: if the apparatus is movable relative to the ether with the velocity *v*, the time *t* depends on the orientation of *sc* as regards the velocity *v*; it is not the same when *sc* has the same direction as the movement of the earth, (Fig. 2) and when *sc* is perpendicular to this motion. Michelson measured the differences between these two times by an interferential method.

The experiment was made at Cleveland[2], it gave a negative result, the time *t* was the same in all the positions of the apparatus. The precision of the experiment being granted, Michelson was in a

position to affirm that the relative movement of the earth was inferior to 7.5 km. per second.

Cleveland is in the state of Ohio on the shore of Lake Erie at 180 metres above sea level.

Admitting that the entire solar system is displaced as regards the ether; if at the moment Michelson made his experiment the velocity of this current of ether as regards the solar system had had the same magnitude and the same direction as that of the earth, his result is found to be explained; but six months later the velocity of the earth being found to have changed in direction, the experiment ought to have given a positive result and put in evidence a relative velocity double that of the earth in its orbit, that is to say, of 60 km. per second.

But the experiment of Michelson gave a negative result at all the seasons of the year.

Theory of Michelson's Experiment.

Figure 1 represents the arrangement of the apparatus. s is a luminous source; a a semi-transparent plate; c and b are mirrors; d the observer; $ac = ab$. A first ray travels the path $sabad$; a second travels $sacad$; these two paths are equal if the apparatus is at rest. Figure 2 is traced in fixed ether. Suppose the apparatus carried along with velocity v in the direction sc. The two rays depart from s at the instant t_0, reach a at the instant t_1; the first ray will reach b at the instant t_1; return to a at the instant t_3. At this moment a has arrived at a_1. The duration of this passage is $2l/(\sqrt{c^2-v^2})$, where c is the velocity of light and l is the distance ab or ac (Fig. 1). The second ray will take to traverse aca_1 the time $2lc/(\sqrt{c^2-v^2})$. It will arrive then later by $2l(v/c)^2$. If λ be the wave-length of the light used, the change in the fringes when the apparatus is turned through 90° is $2l\,(v/c)^2 \div \lambda$.

In Michelson's experiment $l = 1100$ cm., $v/c = 2 \times 10^{-4}$, $\lambda = 5 \times 10^{-5}$ cm., and the predicted change was 1.6 fringes.

Relativity

To explain Michelson's result three hypotheses were put forward:—

1. The contraction hypothesis of Lorentz: the length *sc* is shortened when its direction follows that of the velocity *v*; the contraction is such that the time *t* is independent of the direction *sc*.

2. The theory of restricted relativity: the classical kinematics is not to be relied upon. Minkowski and Einstein constructed a new theory which explained not only the experiment of Michelson, but many other phenomena. It suppressed the idea of the ether. It illuminated electro-dynamics with a new day. It has been verified by experiments of which we shall speak again.

3. To avoid the two preceding hypotheses Lorentz and Planck came back to the idea of Stokes: the ether is dragged along by the earth. In the interplanetary space the ether is fixed, and at the terrestrial surface this medium participates almost entirely in the movement of the earth; these two regions are separated by an intermediate zone where the ether is dragged along partially.

The physicist Lodge, a partisan of the mechanical theory of the ether, attempted to put experimentally in evidence this dragging along of the ether by a mass of lead in movement; the experiment did not show any dragging.

It could be replied that the masses with which Lodge operated were extremely small in comparison with that of the earth; it is possible that such feeble masses do not drag the ether; the mass of the earth, which is incomparably more important, might drag it. Planck attributes in effect the dragging along of the ether by our planet to the attraction exerted by this latter upon the particles of the ether; the attraction exerted by a mass of some tons is negligible in face of gravity.

The Experiment of Miller.

In 1904 Miller repeated the experiment of Michelson at Cleveland; the result was always negative; the interferometer of Miller was more accurate than that of Michelson: a relative velocity of 3.5 km./sec. would have produced an appreciable displacement of fringes.

In 1905 Miller repeated the experiment at Cleveland[3] on Mount Euclid, 100 metres higher than in the preceding year; he observed this time a slight effect corresponding to a relative velocity equal

to 1/10 of that of the earth in its orbit. The result appeared doubtful to him; he resolved to transport the interferometer to an isolated mountain.

From 1921 to 1925 the experiment was repeated at Mount Wilson at an altitude of 1700 metres; a positive result this time:[4] Miller established a relative velocity of ether equal to 1/3 of the velocity calculated if the ether were fixed.

This experiment seems to confirm the theory of the partial dragging along of the ether. The ether seems dragged along almost completely by the earth at an altitude of 200 metres; it seems to participate but to 2/3 the velocity of the earth at an altitude of 1700 metres. What is the direction of this current of ether? We are unable to say anything on this subject. Miller has so far only published the results of the observations made in April 1921 and in April 1925. Only the comparison between the results obtained at different epochs of the year would permit us to establish a conclusion.

Aberration.

Let us admit the hypothesis of Stokes and Lorentz. A ray of light coming from a star falls upon the earth; it is displaced in a straight line in the region of the ether which is not troubled by the movement of the celestial bodies. But in this intermediate zone which surrounds the earth and where the ether is partially dragged along our ray will be deviated, as a vessel which traverses a current is deviated from its course. When it arrives at our globe it will no longer have the same direction. Observation has made evident the existence of precisely such a deviation: aberration.

The hypothesis of the fixed ether has permitted us to give an explanation which was classic till our days. The theory of relativity leads to the same result. The law of aberration calculated by the one or the other of these two hypotheses is in agreement with observation.

Is it the same with the hypothesis of the dragging along of the ether? Since we do not know the law of this dragging along we cannot reply to the question. We content ourselves to seek a law of the dragging along of the ether which would account for aberration.

Mathematically, the question presents no difficulties[5]: it is necessary and it suffices,

1. That the velocity of light waves be independent of the density of fluid ether.

2. That the movement of this fluid be irrotational. Recall briefly what is meant by that.

Consider a fluid in movement; imagine that the following fictitious operation is made: we solidify suddenly the part of the fluid inside a very small sphere S and annihilate the rest of the fluid. The solidified sphere S will take a rectilineal uniform movement of translation on which is superposed a movement of uniform rotation around an axis passing through its centre. The axis of this rotation and its length define the "rotational" of the movement of the fluid. The movement is irrotational if this fictitious rotation is nil.

Such must be the case of the ether in order that aberration might have the observed value.

Notice that the classic law of aberration is verified with great exactitude; it intervenes effectively in the catalogues of fundamental stars; the observed duration differs from the calculated deviation by less than $0''.1$.

The two imposed conditions do not suffice to determine the law of the dragging along of the ether; the irrotational movement of a fluid is not known unless its density is given in all points of space; we do not know this density.

Per contra, we must impose on the ether the following conditions: On the earth's surface the velocity of the ether differs very little from that of the earth. On a sphere of sufficiently great radius, (for example, double that of our globe) the velocity of the ether is almost nil.

Analysis permits us then to establish the following result: it is not possible to admit that the ether is incompressible. And further, the density of the ether must vary in very great proportions: the density of the ether at the surface of the earth must be at least seven times greater than its density in interplanetary space. There is a serious difficulty if we assume that this variation of the density of the ether must not lead to any change in the phenomena of light.

The other Data of the Problem.

Modern ideas regarding the nature of light are more and more opposed to the assimilation of the ether to a vibrating fluid. But this is but a theoretical proof against the ideas of Stokes and of Planck: that perhaps the photo-electric effect may be put in accord with the hypothesis of the existence of the ether we cannot deny *a priori*.

I have reserved for the end the principal argument against the dragging along of the ether.

The Experiment of Michelson and Gale.

Represent upon the surface of the earth in the northern hemis-

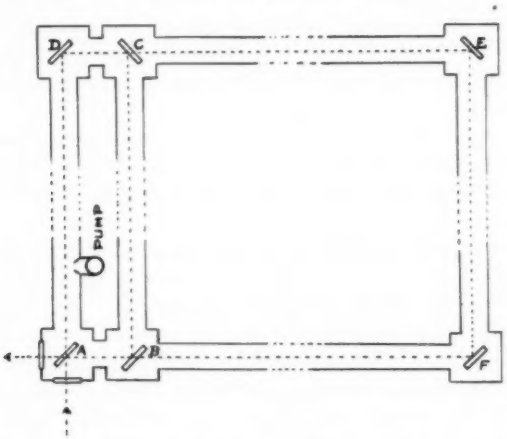

Fig. 3. Arrangement of the apparatus of Michelson and Gale.

The rays of light traverse a vacuum. The apparatus comprises two light circuits: a greater circuit *AFED* and a lesser circuit *ABCD*. The experiment consists in comparing the fringes produced by these two circuits.

phere a rectangular contour *AFED* (Fig. 3), *AF* and *ED* are two arcs of meridian, *FE* and *AD* two arcs of parallel, the latitude; *FE* is greater than that of *AD*, *DE* is west of *AF*. Suppose the ether fixed.

A ray of light follows the course *ADEFA*, a second ray traverses *AFEDA*. The two rays take the same time to traverse the arcs

of meridian AF and ED. The first ray will take less time to traverse AD than the second to traverse DA, for being carried forward by the rotation of the earth, D will seem to come to meet the first ray, while A will seem to fly from the second.

The advance of the first ray upon the second will not be exactly compensated by the analogous phenomenon which will be produced by the traversal of FE for FE is smaller than AD and the velocity of F in the rotation of the earth is inferior to that of A.

If the two rays leave A at the same time the first will come back later than the second. The retardation of this last ray is measured by an interferential method. This experiment permits putting in evidence the rotation of the earth in comparison with the ether.

For a relativist it puts in evidence the rotation of the earth with respect to the Galilean axes: the theory of restricted relativity predicted in effect for the second ray a retardation equal to that predicted by the theory of the fixed ether.

The experiment was made at Clearing, Ill., in 1925 by Michelson and Gale.[6] AF had a length of 338 metres and AD 611 metres. The theory predicted in this case a displacement of fringes of 0.236 fringe (± 002). The mean of 269 observations well grouped has given a displacement of 0.230 fringe (± 0.005).

The agreement is excellent.

If the ether had been partially dragged along on Mount Wilson, the displacement observed, without being nil, would have been different. If we admit the existence of the ether as a fluid medium, the experiment of Michelson and Gale proves that this fluid is not dragged along.

The three Hypotheses Compared.

Let us compute the chances of the opponents.

The theory of restricted relativity has for it:

1st—The experiments of Kaufmann and Bücherer[7] on the β rays of radio-active bodies, and those of Eug. Guye and Lavanchy upon the cathodic rays. These experiments have established the variation of the mass of an electron with its velocity according to the law predicted by relativity.

2nd—The structure of spectrum lines. Sommerfeld[8] has proved

that the dynamics of relativity account for the structure of the hydrogen lines and the spectra of X-rays.

3rd—The experimental verifications of the theory of Einstein.

It has against it: The experiment of Miller.

The theory of the fixed ether has for it: The experiment of Michelson-Gale.

Against it: Those of Michelson (1885) and of Miller (1921).

The theory of the ether dragged along has for it: the experiments of Michelson (1885) and of Miller (1921).

And against it: The experiment of Michelson and Gale.

Aberration and the "dragging" of waves remain neutral. Nevertheless relativity gives more simple explanations.

Conclusion—The opponents of relativity are hopeful. The relativists are confident; they recall what obstacles the law of Newton encountered at its beginning. We have seen that neither the theory of fixed ether, nor that of the dragging along of the ether is acceptable. The theory of Minkowski and of Einstein has nothing against it but the experiment of Miller. But the generalized relativity of Einstein has not yet given its reply.

We ought to wait; it is to be hoped that new experiments will decide the question. Perhaps from these a common explanation may be found to satisfy all the known facts.

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Paris.

REFERENCES

[1]Stokes, *Works. V. II.*
[2]*Philosophical Magazine*, 1887.
[3]*Philosophical Magazine*, May 1905.
[4]Proceedings of the National Academy of Sciences, June 1925.
[5]See various notes: *Comptes rendus* of the Academy of Sciences, 1925, 1926.
[6]*Astrophysical Journal*, April, 1925.
[7]*Annalen der Physik*, Vol. 19, p. 487, 1906.
[8]*Atombau und Sspectrallinien.*

NOTES AND QUERIES

Communications are invited, especially from amateurs. The Editor will try to secure answers to queries.

PRECESSION OF THE EQUINOXES DISCOVERED BY THE BABYLONIANS.

It has been usual to attribute to Hipparchus the discovery of the precession of the equinoxes; but in a letter to *Science*, Professor Florian Cajori gives reasons for believing that this phenomenon was observed by the Babylonians. Professor Cajori's communication is as follows:—

Recently it has been shown[1] that the slow motion of the equinoctial points on the ecliptic, called the precession of the equinoxes, was first discovered before the time of Hipparchus, by a Babylonian astronomer *Kidinnu* (sometimes written *Kidenas* or *Cidenas*), who directed an astronomical school at Sippra, on the Euphrates, about 343 B.C. This Babylonian achievement has been suspected for some years, but no definite conclusion had been reached, because of uncertainties relating to the interpretation of astronomical records[2]. The final settlement of this question has become possible by the examination of some new Babylonian tables.

The fact that the astronomer *Naburiannu* (about 508 B.C.) fixed the equinoctial point at 10°, and Kidinnu, about a century and a half later, at 8°, the zero point on the ecliptic being interpreted as the same in both cases, shows that Kidinnu had a knowledge of the precession of the equinoxes. A study of tables indicates that from that time on, in the ephemerides following the system of Kidinnu, the zero point on the ecliptic was shifted from time to time, to enable astronomers to retain the same angular value for the beginning of the autumnal equinoctial years. This again implies a knowledge of precession. A table (VAT 7821) prepared not later than 186 B.C., and based on the Kidinnu system, gives solar longitudes from day to day, differing by 59′9″, an amount in excess of the true average value of 59′8″9‴.6 for a sidereal year, which was estimated by Kidinnu to be $365^{d}6^{h}13^{m}43^{s}$. This excess was corrected in the table by taking on a certain day 56′9″ in place of 59′9″. Thus the computer of the table took the average daily velocity of 59′9″ to yield in the course of one

[1] Paul Schnabel, "Kidenas, Hipparch und die Entdeckung der Präzession," *Zeitschrift für Assyriologie*, N.S., Vol. 3, April, 1926, p. 1-60.

[2] F. X. Kugler, "Sternkunde und Sterndienst in Babel," II Buch, II Teil, 2 Heft, 1924, Anhang II.

year, not exactly 360°, but an additional 3'. Dividing 360°3' by 59'9", and allowing liberally for certain possible sources of error, Schnabel concludes that the year considered by the computer could not have exceeded $365^{d}5^{h}30^{m}$. The modern value for the equinoctial solar year is $365^{d}5^{h}48^{m}45^{s}$. Thus the Kidinnu astronomy had two years, the sidereal and the equinoctial. Kidinnu deserves to be ranked among the greatest astronomers of ancient times.

NEPTUNE

Measured and slow is this dim python's crawl,
  Journeying afar upon the utmost bourne
  Of the sun's realm. How lonely, how forlorn,
In his vast path that forms the outer wall
Fronting the trackless depths of space, from all
  His brothers' company forever rudely torn—
  No phosphor lights to grace his shadowy morn
Ere the star-parent's pale rays feebly fall.
Sad world, unseen, unloved he still might pass
  Deep hidden in the vast where darkness broods,
But for the prying of the trusty glass,
  That scans the mist across infinitudes
Of cosmic birth, and knows this tenebrous mass,
  Exiled for aye to glacial solitudes.

GEOFFREY BELL.

Paris, Ont.

MEETINGS OF THE SOCIETY

AT TORONTO

The regular fortnightly meeting of the Royal Astronomical Society of Canada was held on Tuesday, February 1, Mr. A. F. Hunter, the President, in the chair.

The following were elected to membership: W. L. Haight, Esq., K.C., Parry Sound, Ont.; Mr. J. H. Dent, Parry Sound; Mr. C. E. Armstrong, Parry Sound; Mr. E. B. Graham, Brampton, Ont.

Mr. Hunter announced that the eastern elongation of Mercury could be observed on the 25th of February and it would be then most favourably placed for observation as an evening star.

Mr. Gore told of his observations on the 25th of January of a well-defined Sun Pillar reaching 30 degrees above the horizon. The sun at the moment of observing appeared about 5 or 6 degrees from the setting point.

Mr. Hunter then introduced the speaker of the evening, Prof. N. E. Sheppard, of the University of Toronto. His subject was "The Mechanism of the Solar System."

The physicist and mathematician had long endeavoured to find a mathematical formula to account for the observed phenomena as presented by the motions of the planets. In the problem three fundamental ideas obtained: Time, Space, Mass. Other terms were used: uniformity, motion and volume. These were conventions on which all were agreed. Prof. Sheppard exhibited a model of a cone which had been cut up in sections. These conic sections are the circle, the ellipse, parabola, hyperbola, all of which figures were found in the orbits of the bodies revolving in the solar system.

He cited Kepler's laws: 1st that the orbit of every planet is an ellipse, with the sun in one of the foci; 2nd that an imaginary line drawn from the sun to a planet will sweep over equal areas in equal times. Prof. Sheppard also pointed out that a body once set in motion with a certain velocity would tend to continue at a uniform rate unless acted upon by some other force. He then explained Newton's law of gravitational force and showed that the deviations in the planets' orbits were due to the attractive force of the sun and also of the other planets in a very minor degree.

Some discussion followed in which Mr. W. Gore made some interesting observations. He said that the well known law of gravitational attraction as represented by the expression Gm_1m_2/d^2 which had been used by Prof. Sheppard in his instructive discourse appeared to relate to a space without any other property than that masses could exist in it and their distances could be measured. There were however some astronomical facts which appeared to indicate that

space had some further properties which might modify to a small extent gravitational attraction as represented by the simple law. Some of these facts such as the motion of Mercury's perihelion and the bending of the line of sight while passing a large mass had been successfully treated mathematically by Einstein without indicating a physical explanation.

There were some other facts such as the almost circular paths of the planets and the apparent spiral motion in some of the nebulae.

The observed constant, or nearly constant, rate of propagation of light and electricity across space indicates that it has elastic properties; and it has been a matter of interest to the speaker to consider in what way the simple gravitation law must be modified if it is propagated by some elastic quality at the speed of light and he had arrived at the following modified law of attraction between a very large mass m_1 and a very small one m_2

$$\text{Gravitational attraction} = \frac{Gm_1 m_2}{d^2} \cdot E^{-Kd} \sqrt{1 + \frac{v^2}{C^2} + \frac{v^r}{2C}}$$

The first factor is the usual simple law. The second indicates gravitational fading, of importance only at vast distances quite beyond the solar system. The third is of importance only over short distances and long periods of time.

E is the base of the Napierian logarithms.

K is an exceedingly small fraction depending upon the elastic qualities of the ether.

d is the distance apart of the two masses.

v is the velocity of the small mass.

C is the velocity of light or of the transmission of gravitational attraction.

v_r is the radial velocity of the small mass in relation to the larger measured positive when outwards and negative when inwards.

The quantity under the root-sign indicates a forward movement of the line of apses in an elliptical path which changes with the radial velocities, it being greater for outward than for inward movements.

It is difficult to determine the precise effect of these two additional factors over a very long period of time upon the form of the path of a gravitating particle. A trial method using exaggerated coefficients appeared to indicate that an elliptical path would gradually become circular with a gradually changing radius.

Prof. Chant drew attention to the suggestion being entirely hypothetical to which Mr. Gore assented.

March 1—The meeting was held in the Physics Building of the University at Toronto, at 8 p.m. The President, Mr. A. F. Hunter, in the chair.

The assistant-librarian reported ninety-two periodicals received during the months of January-February.

The President, after speaking of the predictions of phenomena, drew the attention of the members to the fact that the present time of the year is favourable for the observation of the Zodiacal light—just after sunset when the sky is clear.

The paper of the evening was presented by R. A. Gray, M.A., on "How to paint an Eclipse of the Sun".

Mr. Gray discussed the difficulties encountered by an artist in attempting to paint a solar eclipse. Many hours are required in painting a portrait or a landscape, whereas a total eclipse lasts often less than two minutes and the opportunity of painting one occurs at rare intervals in a lifetime. The painter must work at high speed, and be thoroughly prepared to observe accurately not only the form and position of the corona and prominences, but also note very rapidly their colours and their values, as well as those of the clouds, the moon and the sky.

Some scientific scheme of colour such as Munsell's must be employed and by some system of shorthand the colours are noted on charts prepared prior to the time of the eclipse.

Mr. Gray described Munsell's colour system and showed from the Munsell atlas about 600 different colours. The ability to recognise these colours accurately and rapidly was an essential qualifica ion for those who essayed to paint an eclipse.

March 15.—The regular meeting was held in the Physics Building of the University, at 8 p.m., the President, Mr. A. F. Hunter, in the chair.

The President referred to the death of Mr. Wm. Bruce of Hamilton, at the age of 94. Mr. Bruce was a native of the Shetland Islands. He was a most interested student of astronomy, and a most valued member of the Society for many years. It was resolved that a letter of condolence be sent to the family, and a committee composed of Mr. Hunter, Mr. Miller and the Recorder was appointed.

Under predictions of Phenomena, Mr. Hunter remarked that Venus was a fine object in the evening, and that the Pons-Winnecke Comet would be a naked eye object in June of this year; this comet has a period of 6 years.

Mr. Collins made reference to Prof. E. W. Brown's article in a recent issue of one of the science journals in which he stated that his calculations showed a slowing up in the earth's rotation.

The paper of the evening was by Dr. John Satterly on "Radiation and High Temperature Measurements." This address was fully illustrated with lantern slides and experiments.

After a short talk on radiation generally, experiments were done showing that black bodies are good emitters and good absorbers. The first experiment used a piece of platinum foil upon which was written a letter A in black ink, when the foil was placed in the large flame of a Meker burner, the A glowed brighter than the rest of the foil. For the second experiment two equal air thermometers were employed (corked glass flasks provided with glass tubes dipping into a little coloured water); one flask was painted dead black, and the other coated with thin tinfoil. When exposed to the radiation from a hot plate the blackened thermometer showed the greatest movement. The ether thermoscope of Leslie and the pyrheliometer of Violle were also shown. Dealing with later work, the development of thermoelectric currents, the thermopile and the galvanometer were illustrated with pieces of iron and copper wire linked together in a circuit with a home-made reflecting galvanometer (as made by the students of the Royal College of Science, London). The spot of light travelled across the

screen, the movement being proportional to the current, and hence to the difference of temperature between the junctions, and hence, when the one junction is blackened and exposed to radiation, to the incident radiation which falls on the junction. The standard thermopile of some years ago (made by Golaz of Paris), the Crookes' radio meter or "light mill" and the linear thermopile (Adam Hilger, London) were then used to measure respectively the radiation from a red-hot iron ball and the intensity of the radiation at different parts of the spectrum. Dealing with the ball the law of the inverse square of the distance was demonstrated, and it was also used to exemplify Stefan's law, namely, that the strength of the radiating stream from a black body was proportional to the fourth power of the absolute temperature.

For the energy distribution experiment a large direct vision spectroscope was used to throw a sprctrum of the carbon-arc lamp on the screen and by passing the linear thermopile across it the energy intensity at different places, as indicated by the current in the galvanometer, was shown to be very small for the blue end of the spectrum, larger for the red end, larger still for the infra-red and gradually fading away beyond that.

Herschel's early work on energy distribution was recalled, also Langley's work with the bolometer. A typical black-body energy distribution curve was drawn on the black-board and Wien's law $E_\lambda = c_1 \lambda^{-5} \epsilon^{-2}/\lambda\theta$ explained. In this formula θ is the temperature of the black body, E_λ the intensity of the radiation of wave length λ, and c_1 and c_2 are constants. With the same notation the total energy of the spectrum $E = \int_0^\infty E_\lambda d\lambda$. This is measured by the area under the curve, and is, by Stefan's law, proportional to θ^4, *i.e.*, $E = \sigma\theta^4$. The application of Stefan's law to measure the temperature of the sun was next illustrated with Violle's pyrheliometer and other radiometers, such as the Boys radiomicrometer, Langley's bolometer and Lummer & Kurlbaum's bolometer, all of which may be used to measure the solar constant, *i.e.*, the energy received per sq. cm. of surface exposed to normal sunlight. It was mentioned that the intensity of sunlight is equal to 7000 H.P. per acre, and that various attempts have been made to capture this power where otherwise it is wasted (as in the desert regions) and use it for the benefit of mankind. Stefan's constant, combined with the solar constant and the sizes of the earth's orbit and the sun's radius, also serve to measure the temperature of the sun.

Fery's total radiation pyrometer, consisting of gold mirror, thermo-junction and focussing device, (Cambridge Instrument Co.) was demonstrated and its use to measure the temperature of furnaces and other high temperature bodies, and even the surface of the sun was illustrated.

Going back again to Wien's energy-distribution curve of a black body, this curve was drawn for black bodies of different temperatures and it was shown how the peak of the curve shifted to regions of smaller wave-length as the temperature went up. This is exemplified in Wien's "displacement law" *viz.* $\lambda_m \theta =$ a constant $= 2890$ if λ is in microns or 289 if λ is in centimetres and θ the absolute temperature in degrees Kelvin. When the energy distribution curve is known

λ_m can be found and therefore θ calculated. For the sum $\lambda_m = .55$ microns and therefore θ is of the order 5300°K. If the intensity of hot bodies is always measured at the same wave-length Wien's equation can be thrown into the form $log\ E_\lambda = A - B/\theta$ so that if measurements are made for two known values of θ, the constants A and B can be determined and the equation then used to determine unknown high temperatures. The intensity of the radiation can be compared with a standard source, either by a wedge-photometer or by first polarising the radiations and passing them through a Nicol prism analyser. For the purposes of demonstration a tubular electrically heated furnace (Baird and Tatlock) was raised up to 1400 C. and the intensity of radiation from a plug of graphite was measured on a standardised direct reading polarising optical pyrometer (Cambridge Instrument Co.). Members of the audience were asked to come forward and take readings and Mr. A. F. Miller kindly obliged. The last form of pyrometer shown was a direct reading disappearing filament pyrometer (Cambridge Scientific Co.). In this pyrometer the appearance of the furnace is watched with a hot tungsten filament in a little lamp within the instrument. The current through this lamp is controlled by a 2-volt cell and a rheostat and when the filament "just disappears" against the background of the furnace the galvanometer needle of the lamp circuit reads on a scale the temperature of the filament (scale furnished by the makers) and therefore of the furnace. In both the optical pyrometer and the disappearing filament pyrometer the radiation passes through a piece of standard red glass so that matches are made for the same wave-lengths. Mr. A. F. Miller also kindly took readings on this pyrometer, and readings of the same plug of graphite looking at both ends of the furnace agreed to within 5 or 10 degrees. Finally the application of these methods to the measurements of planetary and stellar temperatures was taken up.

References were made to the work of Professor Poynting (chiefly mathematical, at Birmingham) and Dr. Coblentz (of the U.S. Bureau of Standards). In the case of stellar spectra, the intensity of each line is measured and plotted and a continuous curve is drawn through the tops of the lines to get the equivalent black body curve, whence the ordinary formula can—in moderation—be applied.

An interesting discussion took place and after the lecture several of those interested came up to the table and repeated the experiments for themselves.

March 29.—The meeting of the Royal Astronomical Society of Canada was held in the Physics Building of the University at 8 p.m., the President in the chair.

The following were elected to Membership in the Society:—

Mr. James Grant, 27 Daykin Block, Winnipeg;

Mr. Otto W. Naegele, 2262 Houghton Avenue, Bronx, N.Y. City.

Under "Observations" Mr. Hunter reported having observed on a recent occasion a double image of the sun shortly before sunset. This was attributed to unequal refraction of the atmosphere.

Recent attempts to redetermine the rotation periods of Venus and Mercury were described.

The paper for the evening was by Mr. John Patterson, M.A., of the Meteorological Observatory on "Solar Radiation and the Weather." Mr. Patterson pointed out that whilst the meteorologist admitted that we are dependent on the sun's radiation for weather conditions the accurate determination of any variations of such radiations was very involved on account of the fact that the observer is of necessity enclosed in the earth's atmosphere, whose thermal conditions are inconstant on account of the varying local conditions. When it is possible to take observations outside the earth's atmosphere, the lecturer thought, would the conditions be sufficiently stable to definitely determine whether the solar radiations are variable or not.

The assistant Librarian drew the attention of the members to a number of interesting articles that had recently appeared in various publications received in the Society's Library.

E. J. A. KENNEDY, *Recorder*.

AT WINNIPEG

February 4, 1927—The meeting of the Winnipeg Centre was held in Lecture Theatre "A" University Science Building. The speaker of the evening was Dr. L. A. H. Warren, who took as his subject "The Evolution of Worlds." The following is an abstract of the lecture:—

Professor Warren first described some of the ancient conceptions of the world, those of the Hindoos, the Egyptians, the Chaldeans and the Greeks being illustrated on the screen.

For about fourteen centuries (from 130 A.D. to 1500 A.D.) men thought that the earth was the centre of our system and that the sun revolved around it once a year. This Ptolemaic theory held sway until Copernicus showed that it was our sun which was the central body, and that the earth and other planets revolved around it. Bit by bit was added to our knowledge of the movements and the physical nature of our planets. The lecturer gave a detailed description of our solar system as it is known to-day, the eruptive activities of the sun receiving special attention.

The most generally accepted theory to-day of the origin of the members of our solar system is known as the "Planetesimal Hypothesis" and was first put forward about 25 years ago by Professors Chamberlain and Moulton of the University of Chicago. According to this theory all the members of our solar system were once part of the sun. Under great tidal strains caused by the passing of another star, or sun (all stars are suns), large masses of gas ejected from our sun were drawn so far out that the gravitational pull of the sun was not sufficient to draw them back. By the pull of the passing star these masses were given a forward motion and a rotational motion which caused them to revolve about the central sun, and to rotate on an axis. These great masses of gas formed the beginnings of our planets. They gradually drew in the small masses

(planetesimals) that came near them. Thus they grew in size, and are still growing slowly through the accretion of tiny particles, over twenty millions of which, it is estimated, fall into our earth every day as "meteors" or "shooting stars." The smaller of these great masses of gas cooled faster, becoming solid at least at their surfaces, giving us our minor planets Mercury, Venus, Earth, and Mars. The greater masses are still largely in a gaseous state, so that their densities are quite low. This is the condition in which we find our four major planets Jupiter, Saturn, Uranus and Neptune to-day.

Dr. Warren also showed the structure of our great Galaxy or "Milky Way," containing several billions of stars or suns, and pointed out that our old sun was just one of this myriad host of suns, wending its way to and fro through the galaxy, at a speed of about 400,000,000 miles per year. During the past two years it has been shown that far beyond our galaxy there are at least five other great systems of suns comparable to our galaxy in size and structure. It seems quite possible that each of the 300,000 known spiral nebulas, so-called, which lie outside our stellar system may be a separate stellar system, but direct proof on this point may have to await the construction of the more powerful telescopes now being planned.

The lecture was illustrated with about 75 lantern slides.

The regular monthly meeting of the Winnipeg Centre was held in Theatre "B" Science Building, on Wednesday, March 9th, at 8.15 p.m.

The President, Mrs. E. L. Taylor, was in the Chair.

Mr. L. E. Murray, 607 Broadway, was elected a member of the Society. The Speaker of the evening was Mr. D. R. P. Coats. His subject was "Richard Anthony Proctor, His Life and Works."

Mr. Coats first paid tribute to the work done throughout the continent by amateur radio operators, and introduced to the audience Mr. William Duffield, an amateur, who had on many occasions sent messages to and received messages from brother amateurs in Cape Town, South Africa, in Australia and in New Zealand. Mr. Duffield brought his radio into the lecture hall and got into communication with Arlington, Virginia, and other places.

Mr. Coats, who is a grand-nephew of the celebrated English Astronomer, Richard Anthony Proctor, commenced by giving a brief outline of the childhood and earlier years of the scientist. His studies, said the speaker, were varied, and included mathematics, history, poetry and astronomy. In 1863 he made his literary debut with an article entitled "The Colours of Double Stars," and published during the following year a treatise on "Saturn and His System." It is interesting to know that the first review of "Saturn and His System" appeared in "All the Year Round" and was written by

Charles Dickens. His publications, which were of a popular character, had a wide influence in making the public familiar with the main facts of astronomy.

In 1866, Mr. Proctor was elected a Fellow of the Royal Astronomical Society, became Honorary Secretary in 1872, and to its *Monthly Notices* he contributed many papers on such problems as "The Construction of the Milky Way"; "The Distribution of Stars and Nebulae"; "The Proper Motion of Stars", etc. He was an expert in all that related to map drawing, as is shown by his charting of some 324,000 stars, a work which occupied 400 hours.

The famous astronomer died in New York in 1888 at the age of 51 years. His work of lecturing was carried on for a short time by his widow. His daughter, Miss Mary Proctor, has faithfully followed in her father's footsteps, and is well known as a writer and lecturer on astronomy. Like her distinguished father, she too was elected a Fellow of the Royal Astronomical Society.

The address was illustrated by a large number of slides, and on its conclusion, a hearty vote of thanks was given to the Lecturer.

S. C. Norris, *Secretary.*

LONDON CENTRE

At the January meeting Dr. Kingston gave an address on "The Zodiac." He pointed out that there are two fundamental motions of the earth, viz., the daily rotation on its axis and its yearly motion about the sun. The earth behaves like a gyroscope; the spinning tends to keep the axis of spin in a constant direction. A planetarium was used to illustrate the earth's motions. Space is teeming with solar systems, yet we speak of the celestial sphere of stars,—this is for convenience. If we think of the plane of the earth's equator as extended out into space, we get the position of the celestial equator, which is of necessity a fixed circle. By using a celestial sphere which was constructed by Mr. T. C. Benson, Dr. Kingston was able to demonstrate clearly the celestial equator, the celestial ecliptic and the star portions of the sky which form the signs of the Zodiac. Objects placed on the celestial sphere denoted the principal first magnitude stars. Mr. Benson and Mr. Rowley were thanked by the members for the celestial sphere which helped so much in making the different parts of the address so readily understood. The numerous questions which followed the address were a good indication of the interest awakened in the subject.

E. T. White, *Sec.-Treas.*

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